A PRODUCTION PLANNING MODEL FOR A GOVERNMENTAL AGENCY WITH MULTI-PRODUCTION FACILITIES

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THESIS

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ABSTRACT

A decision model is formulated for the planning of production for a large centrally managed governmental agency with multi-production facilities. The concepts of linear economics and mathematical programming are utilized to develop the model as a single-period planning tool for the efficient allocation of resources and production effort. It is assumed that the governmental agency desires to optimize the conversion of its input resources to outputs for all its production facilities. Under this assumption, the two separate problems of effectiveness maximization and cost minimization for the agency as a whole are considered. The questions of data collection, parameter estimation, and management utilization of the model are also addressed. A specific formulation of the model is presented for the decision problem of the maintenance and overhaul of the major end items of equipment within the logistical system of the Marine Corps.

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I. INTRODUCTION

It is the purpose of this thesis to study one particular type of decision problem for the efficient allocation of resources available to government. The problem selected for consideration is that of the apportionment of production resources for a governmental agency which has multi-production facilities. Production in the context of this paper will conote either actual manufacturing or maintenance and repair.

Production planning and control of the firm has in recent years, been subjected to careful examination using scientific methods. As a result, any industrial concern which desires to be competitive must be on a continuing search for better methods to allocate the resources at its disposal. This seeking of the best or "optimal" allocation of resources has in many cases been achieved by the application of Operations Research methods in concert with sound economic principles. Facilities planning, job scheduling. and inventory control are just a few of the items which have come under close scrutiny by competitive industry.

During this same period, government at all levels has been faced with many of these same operational and planning problems. The allocation of the nation's resources to national defense is an example of where these problems appear with a high degree of regularity. Regrettable many of the

methods of scientific management and decision making, so common in the competetive environment, have not been fully utilized within governmental activities. Hence, this paper is devoted to the consideration of a specific type of resource allocation problem for governmental agencies.

Consider now a hypothetical governmental agency which is centrally managed from some general headquarters. The overall mission of this agency is to provide, by purchase or production, a certain category of physical items. This mission is carried out by the agency at a number of production facilities or by purchasing the items. It will be assumed that at the agency headquarters there are the normal staff responsibilities such as the engineering function and the comptroller function, and that there are sufficient data processing capabilities to carry out the requisite planning for the organization. Production planning is the responsibility of the central headquarters and planning information is disseminated to the production sites of the agency for some fixed planning period. This could be quarterly, semi-annually, or annually. Taken in this context, planning is primarily concerned with determining the mix of manufactured or repaired items which are the outputs of the various production facilities of the agency.

The production sites are a set of governmental requirements facilities whose purpose is to output the requirements as levied on them by the central headquarters. Each of these facilities is assumed to have the same basic production

capabilities in so far as types of items produced is concerned. That is to say that they have roughly the same technological ability, labor skills, production equipment, and availability of input materials. However, due to varying cost of labor and materials and in consideration of the various processes which might be used to produce the same component, the cost of production of a particular component would not necessarily be the same at each of the requirements facilities.

It would be expected that each of the requirements facilities would have a rather standard organizational structure. This could consist of a production force including all the necessary labor skills for producing the various items required, an engineering staff including plant-engineering and maintenance, and a management information group. The latter group would include the normal comptroller functions plus sufficient data processing capability to provide the central headquarters with the necessary raw data for its planning purposes. A facility superintendent with his own personnel staff would manage each of these production facilities and would report directly to the central headquarters. Although the superintendent would be responsible for procedures, methods, and personnel at his facility, he would receive instructions as to the type and quantity of items to be produced from the central headquarters. Generally then, the facility manager would control production, but production planning would be accomplished by the central headquarters.

It will be presumed that for a given planning period the physical production capabilities of each of the facilities are fixed; therefore, the agency's capabilities cannot be increased. Obviously capital investment could expand the production facilities over a period of time, but for a given planning increment they will be considered fixed. This implies that any expansion in production above that which could be accomplished on a regular time basis must come about by the utilization of overtime. Additionally, it will be assumed that the various production facilities will experience no great technological advance during a specific planning period. Hence, none of the production equipment or methods would become outmoded during the planning period.

The central headquarters has a policy of awarding a specific production requirement to that facility from which the agency as a whole derives the greatest benefit or advantage. This implies that each of the requirements facilities are competing with each other for the production of the several items which might be produced for a given planning period. Finally, the central headquarters would consider the use of production sources outside its own facilities if it found this alternative beneficial to the agency as a whole.

Based on the above description of the situation, the decision problem facing the governmental agency may be formalized in the following manner. How can the agency best

allocate the production resources at its disposal, both those at its own facilities and others which the agency might purchase, so that it could place itself in the most favorable position possible?

For the purposes of this paper, the decision problem will be separated into two distinct and all encompassing situations. First, the agency might desire to maximize effectiveness for a given set of resource inputs. In this case, it would be the goal of the central headquarters to determine what mix of products to produce, and where to produce them so as to maximize effectiveness. Secondly, the agency could find itself in the position of wanting to minimize cost for a given set of outputs or items to be produced. This would be the situation when the agency has firm commitments to produce so many items of various types for a given planning period. Under these conditions, the planners for the agency would like to distribute the production requirements among the several production facilities in such a manner that total production costs would be minimized.

The next chapter will present a set of mathematical models which lend themselves to providing solutions to the two decision problems just posed. Subsequently, a chapter will be presented on model parameter estimation techniques and incorporation of the model into management information and decision making systems. This chapter will also discuss characteristic applications of this decision system,

including capital investment questions. A succeeding chapter will be devoted to the development of a decision model for a specific real world management problem of the general type described above.

II. MODEL FORMULATION

A. BASIC CONSIDERATIONS

The introduction has presented a general framework of the situation. From this scenario, specific elements of interest in relation to the model may now be presented. On the broadest demand plane, the agency will have requirements for n products. There will be L product sources available to supply these n products. The agency has at its disposal r production facilities in-house which produce the needed commodities. Additionally, the agency has access to L-r other product sources, outside the agency, from which it may purchase the items required. Therefore, the model formulated should be able to consider both sets of sources.

At each of the agency's production facilities, there are certain scarce resources such as labor, material, and machine tools. It is the intent of the agency to convert these input resources by the most efficient means possible into output products. There are various production activities at each of the facilities to carry out this conversion. These activities consist of specific technological processes which transform the scarce resources into the required outputs.

As related previously, the agency seeks its efficiency objectives by two methods, minimization of cost and maximization of effectiveness. Hence, any formulation must be able to handle both of these cases. Although there are a

number of mathematical programming procedures that might have been chosen to depict the above situation, linear programming was chosen as the technique best modeling the problem. Secondarily, it was felt that linear programming had the inherent adaptability and flexibility to incorporate variations in the decision situation as they might occur.

The general linear programming problem can be stated as maximize: $c^T X$, subject to $AX \leq R$; where X represents a vector of decision variables (the production outputs), c represents a vector of measures of effectiveness, one for each output, R represents a vector of resource inputs, and A represents a matrix of technological coefficients. Certain adaptations of this basic model will be used in this paper to convert it to a cost minimization problem.

B. ASSUMPTIONS

The formulation of the decision model will be based on the following broad assumptions:

1. That the hypothetical agency desires to maximize its total measure of effectiveness, or minimize its total cost. The implication being that the separate production facilities will not optimize singularly but the agency as a whole will seek to optimize its production planning program.

2. That a measure of effectiveness (MOE) can be defined for the production of each product at the several facilities.

3. That the production processes at each facility are readily identifiable and divide the total production effort into a set of mutually exclusive and exhaustive activities.

4. That the agency is centrally planned and can control what is to be produced at each of the facilities for a given planning period.

5. That the planning period is fixed for a specific analysis procedure.

6. That the objective functions and constraints of the mathematical program are linear functions. This requires that the MOE's and the usage of resources be proportional to the level at which each individual production process or activity is operated.

7. That the total MOE for all production facilities, which results from the collective operation of the activities, equals the sum of the individual MOE's from each activity at all facilities, when they are operated on an individual basis.

8. That the total usage for any given resource at each individual facility equals the sum of the quantities consumed by each production activity being operated for that particular resource.

9. That the input coefficients to the model are known parameters. Obviously this is a strong assumption and methods of parameter estimation by means of expected values will be covered later in the paper.

As the paper proceeds, additional assumptions will be presented as required.

C. PROCESS VECTORS

It is now necessary to define the concept of a process vector. This is a column vector which identifies the inputs and outputs for each production activity at every one of the r facilities. There will be n×r of these vectors. Inherent in the formulation of this vector is the assumption that transportation costs between the facilities are infinite once the production of a specific item has begun. In other words, the process vector insures that once production is started on an item at a specified facility, it will remain there until completion of production. However, this concept does incorporate the ability for trade-off among the several distinct production processes for the same resulting output.

As an example of a process vector, consider the general case for the production activity which produces the j^{th} product at the k^{th} facility. A schematic representation of this process vector is presented in Figure 1. Normally the inputs to the process are referred to as technological coefficients. These vector components are known parameters for the model and represent the resource inputs required to output one unit of the j^{th} product.

In this general case, the output 1 will appear in the j^{th} row and the set of technological coefficients for the process will appear in the k^{th} position. If required,

$$\begin{array}{r}\text{OUTPUTS OF PROCESS}\left\{\vphantom{\begin{array}{c}0\\0\\\vdots\\1\\\vdots\\0\end{array}}\right.\\ \text{INPUTS TO PROCESS}\left\{\vphantom{\begin{array}{c}0\\0\\\vdots\\0\\a_{1j}^{(k)}\\\vdots\\a_{mj}^{(k)}\\d_{m+1,j}^{(k)}\\\vdots\\d_{m+s,j}^{(k)}\\\vdots\\0\\0\\\vdots\\0\end{array}}\right.\end{array}\left[\begin{array}{c}0\\0\\\vdots\\1\\\vdots\\0\\0\\0\\\vdots\\0\\a_{1j}^{(k)}\\\vdots\\a_{mj}^{(k)}\\d_{m+1,j}^{(k)}\\\vdots\\d_{m+s,j}^{(k)}\\\vdots\\0\\0\\\vdots\\0\end{array}\right]\begin{array}{l}\left.\vphantom{\begin{array}{c}0\\0\\\vdots\\1\\\vdots\\0\end{array}}\right\}\text{n ROWS}\\ \left.\vphantom{\begin{array}{c}0\\0\\\vdots\\0\\a_{1j}^{(k)}\\\vdots\\a_{mj}^{(k)}\\d_{m+1,j}^{(k)}\\\vdots\\d_{m+s,j}^{(k)}\\\vdots\\0\\0\\\vdots\\0\end{array}}\right\}\begin{array}{l}\text{r SETS OF}\\\text{TECHNOLOGICAL}\\\text{COEFFICIENTS}\end{array}\end{array}$$

Figure 1. The Process Vector

vectors of this type can logically be developed for the L-r production facilities outside the agency itself. To simplify notation, the vector will be represented by $[V_{kj}]^T$ a column vector where j represents the product number and k represents the facility number.

D. CONSTRAINTS

In the formulation of the model, it is required that constraints be developed which will insure that resource application for the various production activities does not exceed available resource quantities. It is the purpose of this section to enumerate the constraint related quantities and to indicate in a general sense their logical place in the model. As discussed above, the model concerns itself with L product sources. The agencies production facilities are the first r sources, while L-r are alternate sources engaged in the same type production effort. The particular source under consideration will be denoted as the k^{th}, where $k = 1,2,...,L$. A superscript on the variable or parameter in question will indicate the k^{th} product source.

Input resources to the model are divided into two separate and distinct categories; labor resources and other limited resources such as material, machine tool hours, and production facility capacity. Additionally, an overall budgetary restraint may be active in certain model formulations. A specific labor resource is designated as the i^{th} quantity, where $i = 1,2,...,m$. The constraint for the i^{th} labor resource at the k^{th} facility is

$$\sum_{j=1}^{n} a_{ij}^{(k)} x_j^{(k)} \leq N_i^{(k)} + O_{ti}^{(k)}$$

where $a_{ij}^{(k)}$ = the amount of the i^{th} labor resource required to produce one unit of the j^{th} output,

$x_j^{(k)}$ = the level of operation of the j^{th} activity,

$N_i^{(k)}$ = the number of units of the i^{th} labor resource available on a regular time basis,

$O_{ti}^{(k)}$ = the number of units of the i^{th} labor resource available on an overtime basis.

The $a_{ij}^{(k)}$'s are given constants. But $N_i^{(k)}$ and $O_{ti}^{(k)}$ may be constants or variables depending on the exact formulation of the model.

The second set of constraints for the model deal with limited resources other than labor resources. There are s of these constraints and a specific one is designated as the i^{th} where $i = m+1, m+2, \ldots, m+s$. The i^{th} constraint for the k^{th} facility appears as

$$\sum_{j=1}^{n} d_{ij}^{(k)} x_j^{(k)} \leq R_i^{(k)}$$

where $d_{ij}^{(k)}$ = the amount of the i^{th} limited resource other than labor required to produce one unit of the j^{th} output,

$R_i^{(k)}$ = the amount of the i^{th} resource other than labor available to the n activities.

As above the $d_{ij}^{(k)}$ are parameters but $R_i^{(k)}$ may be variable or constant depending on problem formulation.

One final constraint which should be enumerated at this point is the budgetary restraint. This restraint will be active when the agency is attempting to maximize its

effectiveness within a certain limited budget. The general restraint function is

$$\sum_{k=1}^{r} \sum_{i=1}^{m} \left[P_{Ri}^{(k)} N_i^{(k)}\right] + P_{oi}^{(k)} O_{ti}^{(k)} + \sum_{k=1}^{r} \sum_{i=m+1}^{m+s} P_i^{(k)} R_i^{(k)}$$

$$+ \sum_{k=r+1}^{L} \sum_{j=1}^{n} x_j^{(k)} P_{Pj}^{(k)} \leq B$$

where $P_{Ri}^{(k)}$ = the cost of one unit of the i^{th} regular time labor resource at the k^{th} activity,

$P_{oi}^{(k)}$ = the cost of one unit of the i^{th} overtime labor resource at the k^{th} activity,

$P_i^{(k)}$ = the cost of one unit of the i^{th} scarce resource other than labor at the k^{th} activity,

$P_{Pj}^{(k)}$ = the purchase price of the j^{th} item from the k^{th} alternate product source,

B = total monetary amount of the budget.

All $P_{Ri}^{(k)}$, $P_{oi}^{(k)}$, $P_i^{(k)}$, and $P_{Pj}^{(k)}$ are assumed to be known constants. The variables of the restraint are $N_i^{(k)}$, $O_{ti}^{(k)}$, $R_i^{(k)}$, and $x_j^{(k)}$. All pertinent expenses to the agency have been included in the constraint. However, the observation should be made that the relevant resource costs are the variable costs and do not include overhead expenses. Specifically sunk costs such as those associated with investments on machine tools, should not be included.

Other constraints will be introduced into the model as they are warranted for a specific formulation.

E. OBJECTIVE FUNCTIONS

In accordance with the introduction, it is intended that the decision model handle both the case where the maximization of effectiveness is the desired result and the situation where minimization of cost is pursued. For this reason, two separate objective functions are developed. First, consideration will be given to the case where the objective is to minimize production and purchase costs for a given vector of outputs $(x_1^*, x_2^*, \ldots, x_n^*)$. Cost in this context is interpreted as the appropriate measure of the value of resource inputs and completed items purchased. This objective function takes the form

$$z = \sum_{k=1}^{r} \sum_{i=1}^{m} \left[P_{Ri}^{(k)} N_i^{(k)} + P_{oi}^{(k)} O_{ti}^{(k)} \right] + \sum_{k=1}^{r} \sum_{i=m+1}^{m+s} P_i^{(k)} R_i^{(k)}$$

$$+ \sum_{k=r+1}^{L} \sum_{j=1}^{n} x_j^{(k)} P_{Pj}^{(k)}$$

where z = the total cost to produce and/or purchase a given vector of outputs $(x_1^*, x_2^*, \ldots, x_n^*)$.

This function includes the same parameters as the left hand side of the budgetary constraint set forth above.

A second objective function is introduced to handle the maximization of effectiveness formulation. This function incorporates the concept that the total measure of effectiveness for the agency is equal to the summation of the effectiveness measures realized from operating the several

production activities at specified levels. Mathematically stated this is

$$Z = \sum_{k=1}^{L} \sum_{j=1}^{n} c_j x_j^{(k)}$$

where

Z = the overall net measure of effectiveness,

c_j = increase in the overall effectiveness that results from each unit increase of the j^{th} output.

Specific points in relation to this function will be presented subsequent to the formulation of the model associated with it.

F. THE DECISION MODELS

Using the functions and concepts developed above, the decision models may now be presented. The mathematical statement of the general linear programming model which seeks to minimize cost for a given vector of outputs $(x_1^*, x_2^*, \ldots, x_n^*)$ is,

Minimize:

$$z = \sum_{k=1}^{r} \sum_{i=1}^{m} \left[P_{Ri}^{(k)} \alpha_i^{(k)} w_i^{(k)} + P_{oi}^{(k)} O_{ti}^{(k)} \right]$$

$$+ \sum_{k=1}^{r} \sum_{i=m+1}^{m+s} P_i^{(k)} R_i^{(k)} + \sum_{k=r+1}^{L} \sum_{j=1}^{n} x_j^{(k)} P_{Pj}^{(k)}$$

Subject to

$$
\begin{array}{c}
x_1^{(1)}\\
x_1^{(1)}\\
{}\\
{}\\
\cdot\\
\cdot\\
{}\\
\cdot\\
{}\\
{}\\
x_1^{(1)}
\end{array}
\left[\begin{array}{c}
V_{11}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}
\end{array}\right]
\begin{array}{c}
+\ x_2^{(1)}\\
+\ x_2^{(1)}\\
{}\\
{}\\
\cdot\\
\cdot\\
{}\\
\cdot\\
{}\\
{}\\
+\ x_2^{(1)}
\end{array}
\left[\begin{array}{c}
V_{12}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}
\end{array}\right]
\begin{array}{c}
+\cdots+x_n^{(r)}\\
+\cdots+x_n^{(r)}\\
{}\\
{}\\
\cdot\qquad\cdot\\
\cdot\qquad\cdot\\
{}\\
\cdot\qquad\cdot\\
{}\\
{}\\
+\cdots+x_n^{(r)}
\end{array}
\left[\begin{array}{c}
V_{rn}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}\\ {}
\end{array}\right]
\begin{array}{l}
+\ x_1^{(r+1)}+\cdots+x_1^{(L)}\geq x_1^*\\
+\ x_2^{(r+1)}+\cdots+x_2^{(L)}\geq x_2^*\\
\vdots\\
+\ x_n^{(r+1)}+\cdots+x_n^{(L)}\geq x_n^*\\
\leq\alpha_1^{(1)}w_1^{(1)}+O_{t1}^{(1)}\\
\leq\alpha_2^{(1)}w_2^{(1)}+O_{t2}^{(1)}\\
\vdots\\
\leq\alpha_m^{(r)}w_m^{(r)}+O_{tm}^{(r)}\\
\leq R_{m+1}^{(r)}\\
\vdots\\
\leq R_{m+s}^{(r)}
\end{array}
$$

$$
\begin{array}{c}
w_1^{(1)}\leq {}^*w_1^{(1)}\\
\vdots\\
w_m^{(r)}\leq {}^*w_m^{(r)}
\end{array}
$$

$x_j^{(k)} \geq 0, \quad j=1,2,\ldots,n, \quad k=1,2,\ldots,L;$

$w_i^{(k)} \geq 0, \quad i=1,2,\ldots,m, \quad k=1,2,\ldots,r;$

$O_{ti}^{(k)} \geq 0, \quad i=1,2,\ldots,m, \quad k=1,2,\ldots,r;$

$R_i^{(k)} \geq 0, \quad i=m+1,m+2,\ldots,m+s, \quad k=1,2,\ldots,r;$

Where for the kth facility during the planning period

$\alpha_i^{(k)}$ = the number of man units of labor per man for the ith labor resource,

$w_i^{(k)}$ = the number of men utilized for the ith labor resource,

${}^*w_i^{(k)}$ = the number of men available for the ith labor resource.

Both $\alpha_i^{(k)}$ and $*w_i^{(k)}$ are input parameters to this model. The other parameters are x_j^*, $P_{Pi}^{(k)}$, $P_{oi}^{(k)}$, $P_i^{(k)}$, $P_{Pj}^{(k)}$, and the components of the process vectors $a_{ij}^{(k)}$ and $d_{ij}^{(k)}$. However, the $R_i^{(k)}$'s $x_j^{(k)}$'s, $O_{ti}^{(k)}$'s and $w_i^{(k)}$'s are considered to be the decision variables for this formulation.

There are two items which should be noted in relation to this model. First, the substitution of $\alpha_i^{(k)}$ $w_i^{(k)}$ has been made for $N_i^{(k)}$ in the constraining functions. This was done to allow $w_i^{(k)}$ to be a variable in the program while still providing for an upper bound on $w_i^{(k)}$ with $*w_i^{(k)}$. Secondly, it is assumed that $P_{oi}^{(k)} > P_{Ri}^{(k)}$, i.e., the cost of labor on an overtime basis is greater than the cost of labor on a regular time basis. This mathematically insures that no overtime labor will be utilized until all regular time labor is consumed.

The second decision model formulated will be that of the maximization of effectiveness for either a variable or fixed set of resource inputs. In this case, a vector of resource inputs may be specified or they may be considered to be decision variables, which will be determined by the program. Mathematically stated, this maximization of effectiveness model is

Maximize:

$$Z = \sum_{k=1}^{L} \sum_{j=1}^{n} c_j x_j^{(k)}$$

Subject to

$$\sum_{k=1}^{r}\sum_{i=1}^{m} P_{Ri}^{(k)}\delta_i^{(k)}w_i^{(k)} + P_{oi}^{(k)}O_{ti}^{(k)} + \sum_{k=1}^{r}\sum_{i=m+1}^{m+s} P_i^{(k)}R_i^{(k)}$$

$$+ \sum_{k=r+1}^{L}\ \sum_{j=1}^{n} x_j^{(k)}P_{Pj}^{(k)} \le B$$

$$\begin{array}{c} x_1^{(1)}\\ x_1^{(1)}\\ \\ \\ \cdot\\ \cdot\\ \\ \cdot\\ \\ \\ x_1^{(1)}\end{array}
\left[\begin{array}{c} V_{11}\\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \end{array}\right]
\begin{array}{c} + x_2^{(1)}\\ + x_2^{(1)}\\ \\ \\ \cdot\\ \cdot\\ \\ \cdot\\ \\ \\ + x_2^{(1)}\end{array}
\left[\begin{array}{c} V_{12}\\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \end{array}\right]
\begin{array}{c} + \cdots + x_n^{(r)}\\ + \cdots + x_n^{(r)}\\ \\ \\ \cdot \qquad \cdot\\ \cdot \qquad \cdot\\ \\ \cdot \qquad \cdot\\ \\ \\ + \cdots + x_n^{(r)}\end{array}
\left[\begin{array}{c} V_{rn}\\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \end{array}\right]
\begin{array}{ll} + x_1^{(r+1)} + \cdots + x_1^{(L)} \ge & 0\\ + x_2^{(r+1)} + \cdots + x_2^{(L)} \ge & 0\\ \vdots & \vdots\\ + x_n^{(r+1)} + \cdots + x_n^{(L)} \ge & 0\\ \le \alpha_1^{(1)} w_1^{(1)} + O_{t1}^{(1)} & \\ \le \alpha_2^{(1)} w_2^{(1)} + O_{t2}^{(1)} & \\ \vdots & \\ \le \alpha_m^{(r)} w_m^{(r)} + O_{tm}^{(r)} & \\ \le R_{m+1}^{(r)} & \\ \vdots & \\ \le R_{m+s}^{(r)} & \end{array}$$

$$\begin{array}{c} w_1^{(1)} \le {}^{*}w_1^{(1)}\\ \vdots\\ w_m^{(r)} \le {}^{*}w_m^{(r)}\end{array}$$

$x_j^{(k)} \ge 0$, $j=1,2,\ldots,n$, $k=1,2,\ldots,L$;

$w_i^{(k)} \ge 0$, $i=1,2,\ldots,m$, $k=1,2,\ldots,r$;

$O_{ti}^{(k)} \ge 0$, $i=1,2,\ldots,m$, $k=1,2,\ldots,r$;

$R_i^{(k)} \ge 0$, $i=m+1,m+2,\ldots,m+s$, $k=1,2,\ldots,r$;

For this model the parameters are $P_{Ri}^{(k)}$, $P_{oi}^{(k)}$, $P_{i}^{(k)}$, $P_{Pj}^{(k)}$, c_j, $*w_i^{(k)}$, $\alpha_i^{(k)}$, and the components of the process vectors $a_{ij}^{(k)}$ and $d_{ij}^{(k)}$. Likewise, the decision variables are the $x_j^{(k)}$, $w_i^{(k)}$, $O_{ti}^{(k)}$ and $R_i^{(k)}$. The column vector of zeroes as a lower bound on the production outputs plays an important role in the model. This allows the agency to drop from its production plan those products which do not make a positive contribution to the total effectiveness measure. Should the input resources $w_i^{(k)}$, $O_{ti}^{(k)}$, and $R_i^{(k)}$ be inserted in the program as constants, then only the $x_j^{(k)}$'s would be the decision variables of the program.

Prior to developing other notions, it would be appropriate to make some remarks pertaining to this model. In this regard it should be observed that the maximization formulation is dependent on the identification and quantification of the c_j's. These parameters are normally referred to as transfer costs. They are value measures which arise in situations where requirements are directed by higher authority and are not subjected to the competitive environment. Almost without exception, utility measures of this type are difficult to define, let alone quantify and measure for use on at least an interval scale. References 1 and 4 discuss at length the wide variety of problems encountered when this problem is broached in the physical world. References 6 and 12 suggest approaches for determining values such as these, but because of the magnitude of this problem it is felt to be beyond the scope of this paper.

Based on the above discussion, no further consideration will be given to determining the values of the c_j's. The maximization of effectiveness model, although formulated will not be applied further in this paper. Henceforth, the thesis will concern itself only with the minimization of cost model. Any reference to the "model" will infer the minimization formulation.

III. MODEL IMPLEMENTATION AND UTILIZATION

A. DATA COLLECTION AND PARAMETER ESTIMATION

A review of the preceeding chapter will reveal that the mathematical inputs to the minimization of cost model were considered to be parameters. However, in an applied decision problem this is not the case and in fact, the inputs are random variables. For this reason, it becomes incumbent upon the user of the model to estimate some property of these random variables so that the resulting estimates might be inserted in the model as known parameters. Therefore, it is the purpose of this section to consider this problem and to suggest statistical procedures to handle it.

As an initial step toward parameter estimation, the model inputs should be classified in accordance with their difficulty of attainment. Three separate categories of inputs were delineated in this regard. First consider that set of parameters which are required when the model user desires to fix input resources. This set of parameters includes the regular time labor, overtime labor, and other scarce resources. Specifically included are $N_i^{(k)}$, $O_{ti}^{(k)}$, and $R_i^{(k)}$. Data for the estimation of these parameters could be extracted from current and future manning level documents, inventory status records, production equipment availability charts, and production facility design layouts.

A second set of estimates required are the per unit cost figures associated with the above mentioned resources, plus the purchase price of items from outside product sources. These parameters are the $P_{Ri}^{(k)}$'s, $P_{oi}^{(k)}$'s, $P_{i}^{(k)}$'s, and the $P_{pj}^{(k)}$'s. Current hourly labor rates, including all variable costs such as fringe benefits and applied overhead, could be used to estimate the cost of labor inputs at the various facilities. Should wage increases be anticipated, proposed hourly schedules would have to be utilized. Material cost data and production machines and facilities utilization cost data, most probably, would be more difficult to obtain. The former data could be obtained from vendor's catalogs and inventory price listings. Equipment utilization cost data might be obtained from production analysis records, or it could be developed by applying industrial engineering study methods to the production processes involved. Lastly, the purchase prices for completed items acquired from outside the agency could be established by price quotes provided by the alternate product sources.

The third set of parameters to be estimated would consist of the technological coefficients of the program, the $a_{ij}^{(k)}$'s and $d_{ij}^{(k)}$'s. Data for the estimation of these values could come from a variety of sources such as engineering performance standards, work sampling procedures, and managerial accounting records. Due to the tremendous number of coefficients that would be required, the extraction of data from accounting records would probably be the most

expeditious and least costly method. However, many accounting systems are implemented in such a manner that the productivity figures extracted from them imply that exactly all the resources were allocated to the several productive work elements. Consequently, they may be unrealistic for indicating the actual required resources for a given production requirement. For this reason, data for the estimation of the technological coefficients may have to be generated by Industrial Engineering type studies. In any case, a rather sophisticated data collection system would be required. As an example, data for the labor technological coefficients would have to be collected by work center for each production output. Information in this detail would not be available in some of the agencies that could be modeled. This would require at the least, a reprogramming of the accounting system.

Based on the above discussion, it may be stated that there are many and varied data sources from which parameter estimates could be made. Collection of data from certain informational areas would be much more difficult and expensive than from others. Many times there will be a positive correlation between the difficulty of obtaining data and its validity. The trade-off between these two factors should be considered in any data collection process. Once an informational source has been identified, data samples may be drawn from it as required. Due to the scope of the

problem envisioned, it is assumed that an automated procedure will be developed to collect the requisite data.

Subsequent to data collection, the actual estimation of parameters may begin. Some type of statistical procedure is required in this instance, as all the model inputs are random variables with unknown distributions, means, and variances. The probabilistic implications are obvious and estimation of parameters immediately becomes a difficult problem. Statistically, it would be desirable to identify unbiased estimators for all of the model parameters. A statistic is called unbiased if "on the average" its values can be expected to equal the parameter it is supposed to estimate. If several unbiased estimators are available, it is desirable to select the "best" of these for estimating a given parameter. "Best" will be used to denote most efficient, where efficient has the following definition:

A statistic $\hat{\theta}_1$, is said to be a more efficient unbiased estimate of the parameter $\hat{\theta}$ than the statistic $\hat{\theta}_2$, if

(1) $\hat{\theta}_1$ and $\hat{\theta}_2$ are both unbiased estimates of θ,

(2) the variance of the sampling distribution of $\hat{\theta}_1$ is less than the variance of the sampling distribution of $\hat{\theta}_2$.

Reference 11 has a more complete discussion of this concept. It can be shown that in most situations met in actual practice, the variance of the sampling distribution of no other statistic is less than that of the sampling distribution of the mean. In other words, in most practical

situations, the sample mean is an acceptable statistic for estimating a population mean μ. This is the procedure suggested for the estimation of model parameters.

Simply stated, parameter estimation will consist of estimating the population mean by using a sample average. A random sample of n observations will be drawn from the data for the total population of a specific parameter. The sample will be then used to calculate the estimate. An estimator for any particular parameter will be defined as:

$$\hat{\theta} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

where x_i is the i^{th} observation of the n observation random sample. This is the basic statistical technique envisioned for the estimation of required model parameters. The random sample from which the estimate was made, would be drawn from data collected during the current or past production periods.

A secondary method of parameter estimation which is a special case of the weighted-average techniques is also presented. This procedure is the exponential smoothing technique which is defined by

$$r^*_{n+1} = r_n + (1-\alpha)r^*_n$$

where

α = a weighting factor; $0 \leq \alpha \leq 1$

r^*_{n+1} = the estimate of the parameter of $n+1^{st}$ period,

r_n = the estimate of the parameter made from data collected during the n^{th} period,

r_n^* = the average value of the parameter estimates for the first n periods.

Probably the greatest advantage of this technique is that it considers estimates made over a number of periods. A second advantage is the possibility of varying the sensitivity to most recent history on a continuous scale by selecting different values of α. One other advantage of this technique is that it requires a minimum storage of historical information. This procedure would most appropriately be applied to estimating the $a_{ij}^{(k)}$'s and the $d_{ij}^{(k)}$'s. By using this technique, the technological coefficients could be predicted more accurately than with single period estimates. Reference 7 contains a more detailed development of this procedure.

The introduction of the paper presumes an adequate data processing capability at each of the facilities. This assumption is implicitly included in the discussion of the estimation techniques described above. Due to the large number of parameters involved, an automated information system would be required at every facility to insure prompt and efficient analysis of the data collected.

B. INTEGRATION OF THE MODEL INTO A MANAGEMENT INFORMATION SYSTEM

The successful utilization of the cost minimization model developed in chapter two is contingent upon several things. These are: inputting reliable paramcters to the

model, availability of a mathematical technique to solve the problem formulated, and once decisions are reached as outputs from the model, providing these decisions to management in the field as guidance in planning their production program. All of these things may be accomplished if the decision model is integrated into a management information and decision system. It is the purpose of this section to present an approach to the development of this system.

The data collection and parameter estimation procedures discussed above would be applicable here. It is anticipated that the management information group at each of the production facilities would accomplish these tasks with computer assistance. One approach to completing these requirements would be to combine the data collection and the parameter estimation into one computer routine. With proper data input and programming, parameter estimates could be output with normal accounting runs. In this way current hourly wage rates, materials usage costs, and technological coefficients could be documented on a single computer runout for a specified data collection period. These parameter estimates could be used for the control, monitoring, and updating of the parameter values already in the model. The approach suggested builds upon the assumption that sufficient data processing capability is available at the facility level to provide management information to the central planning staff.

The situation could arise where certain production processes were not utilized during a given parameter estimation period. For this occurrence, data from previous periods or single valued estimates developed by the industrial engineering and production control departments could be used in estimating the required parameters. A rigorous application of the above broad concepts would enable each facility to develop a complete set of input parameters for itself. These could be prepared for submission and forwarded to the central headquarters by a convenient means such as the mails. The agency's production planning staff would then have an entire set of model input parameters for the facilities at its disposal.

Coincident with the generation of the parameters at the facilities, the headquarters would receive price quotes from the alternate product sources outside the agency. This would have been precipitated by the contracting staff of the agency contacting interested parties and telling them of the agency's production requirements for the next planning period. These other sources would then come back with price bids on the various items they wished to produce for the next period. In this manner, the agency would become cognizant of all alternate production sources and the cost associated with each one.

Once the central agency had all this quantified information available, it would be in a position to begin development of the model for the next planning period. The agency

would now want to determine if there were any special model constraints required for the planning period. If this were the case, the agency might have to contact the facilities or other agencies for additional parameter estimates. Subsequent to this process, the linear program could be formulated in a general sense and then the model could be established on a digital computer for solution. By use of the simplex algorithm, the mathematical program could be solved and an optimal solution obtained. References 3 and 10 present the methodology of the simplex algorithm.

The outputs of the model would be the vectors of resource inputs and the vector of production activity outputs. In mathematical notation these outputs are; $\left[{}^{o}N_1^{(1)}, {}^{o}N_2^{(1)}, \ldots, {}^{o}N_m^{(r)}\right]^T$, $\left[{}^{o}O_{t1}^{(1)}, {}^{o}O_{t2}^{(1)}, \ldots, {}^{o}O_{tm}^{(r)}\right]^T$, $\left[{}^{o}R_{m+1}^{(1)}, {}^{o}R_{m+2}^{(1)}, \ldots, {}^{o}R_{m+s}^{(r)}\right]^T$, and $\left[{}^{o}x_1^{(1)}, {}^{o}x_2^{(1)}, \ldots, {}^{o}x_n^{(1)}\right]$ where the superscript "o" designates the optimal solution. Many of the elements of these vectors could be zeroes indicating no input of a particular resource or an activity level of zero. Included in the production output vector will be the amount of each product to be purchased from each alternate product source.

It should be noted that "optimal" as it is used above refers to a mathematical characteristic of the program. Operationally in the real world a definition of optimality would be impossible to specify. The very nature of the parameter estimates input to the model would insure that the best possible solution would not be obtained.

With the model outputs in hand, the central headquarters would now be in a position to provide planning guidance to the facilities and begin contract procedures with the alternate producers. The appropriate set of model outputs would be forwarded to each facility and an order placed with each alternate product source. In this manner, the information loop would be completed and the producers would have their production plan for the next production period. This overall procedure would recur each planning period and could be considered a continual process over time. A schematic outline of the information and decision system is presented in Figure 2.

In addition to the collective benefits derived from the model, the central agency and the production facilities considered separately could receive meaningful management information from the system. For the facilities the production plans would become the inputs to their actual job scheduling systems. Additionally, these plans would enable the facilities to monitor and control their production in relation to the other facilities. This would be particularly important if a specific item was to be produced at several facilities and a due date was established for that item. Likewise, the central agency could monitor the operation of all the facilities with documents generated from the basic production plans. The agency could also derive management information from the model which would be related to capital investment, investment in resources, and

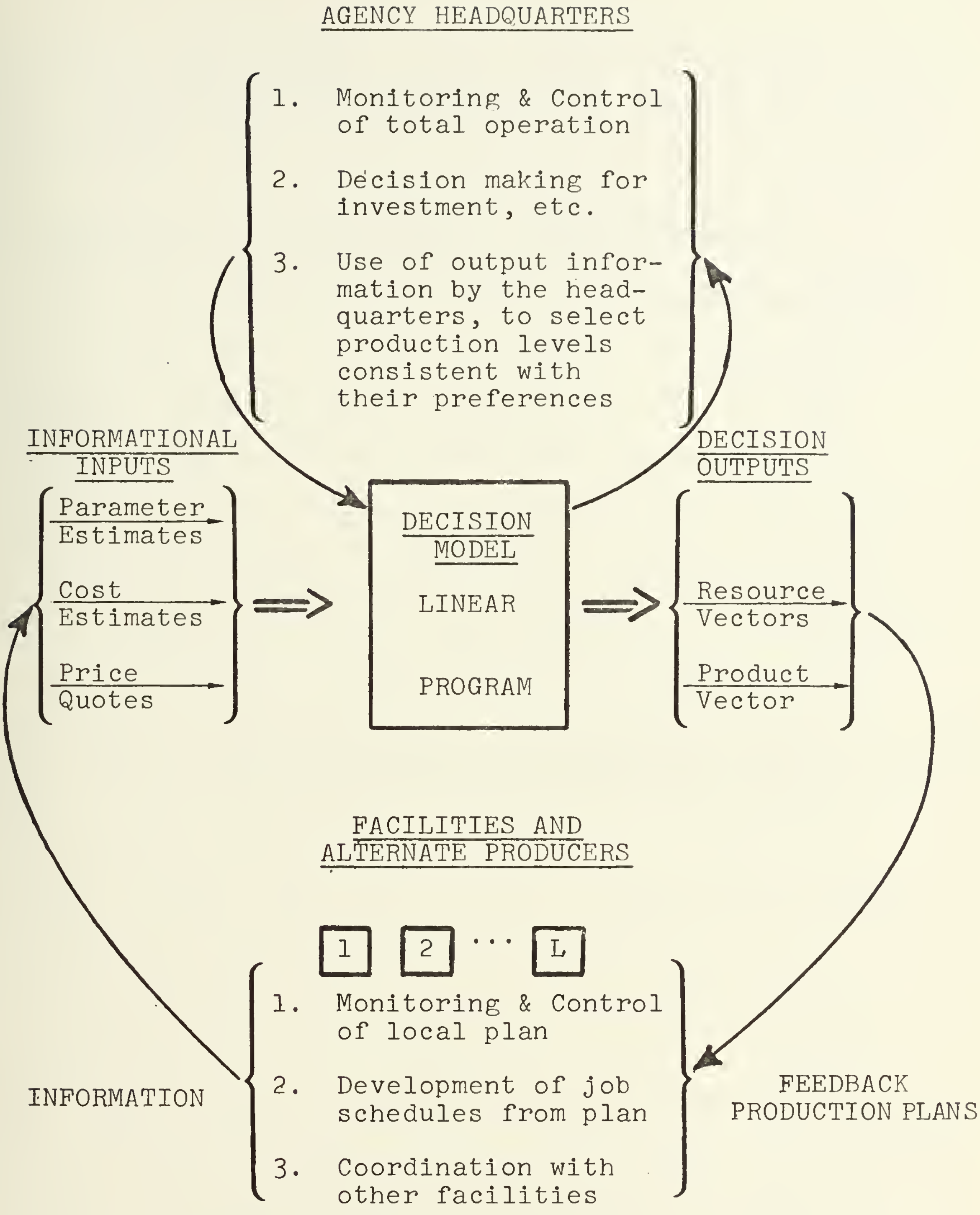

Figure 2. Management Information and Decision System

It should be noted that this diagram represents informational flows for the tth planning period only. Flows for other periods will be continual over time and could be represented similarly.

a number of other items. A more complete discussion of these applications of the model will be presented in the next section.

C. ADAPTABILITY OF THE MODEL TO ACTUAL SITUATION

The basic decision model formulated can easily be modified to handle the changing requirements of the physical situation. As an example, consider that the i^{th} labor resource at the j^{th} facility has been decreased due to a reduction in force. This can easily be reflected in model. A less mundane example could be when a new production process is introduced at one of the facilities. Incorporation of this circumstance only requires the generation of the associated process vector and its insertion into the model. In the same manner, should additional agencies or firms become involved in the production of some of the required outputs, they can readily be considered by adding the necessary terms to the objective function.

Flexibility is also inherent in the model when the adaptive nature of the constraint functions is reflected upon. With proper restraint formulation, the model has the ability to make allowances for such pertinent considerations as government policy, tactical and strategic requirements, and financial limitations. Several examples of the capability are as follows:

1. The constraint to limit overtime at the k^{th} facility

$$\sum_{i=1}^{m} O_{ti}^{(k)} \leq *O_t^{(k)}$$

where $*O_t^{(k)}$ = the fixed overtime limit;

2. The constraint to insure that no fewer than 90% of the hours worked on regular time during the previous planning period will be worked during the current planning period at the kth facility

$$\sum_{i=1}^{m} \alpha_i^{(k)} w_i^{(k)} \geq 0.90 \; *N_{t-1}^{(k)}$$

where $*N_{t-1}^{(k)}$ = the number of man hours worked on regular time during the previous planning period;

3. The constraint to insure that sufficient assets of the jth output are maintained in the field to support the operating forces rather than being overhauled during the planning period,

$$\sum_{k=1}^{L} x_j^{(k)} \leq U_j$$

where U_j = the upper bound on the number of items of the given category to be repaired;

4. The restraint to guarantee that at least 80% of the production of the jth output is accomplished at the agency's facilities

$$\sum_{k=1}^{r} x_j^{(k)} \geq 0.80\ x_j^*$$

5. The constraint to limit total manpower at the k^{th} facility

$$\sum_{i=1}^{m} w_i^{(k)} \leq *W^{(k)}$$

where $*w^{(k)}$ = the fixed manpower level;

6. The constraint to limit total expenditures at the k^{th} facility to a predetermined level

$$\sum_{i=1}^{m} \left[P_{Ri}^{(k)}\ {}_{i}^{(k)} w_i^{(k)} + P_{oi}^{(k)} O_{ti}^{(k)} \right] + \sum_{i=m+1}^{m+s} P_i^{(k)} R_i^{(k)} \leq *B^{(k)}$$

where $*B^{(k)}$ = the fixed budget level.

The above list of constraints is not intended to be a comprehensive study of all possible restraint formulations. However, it is meant to indicate the spectrum of restraints that can be introduced into the model to make it a viable management tool.

D. RELEVANCY TO MANAGEMENT DECISIONS

The primary purpose of the decision model is to determine the decision variables of the program, the resource input vectors, and the product output vector. Management's interest in these particular values would be paramount, but there are a variety of other important uses for the model.

Consideration will now be given to several relevant applications of management interest.

Second only in importance to the decision variables, are the results which can be derived from the duality concepts of linear programming, if the resource inputs are considered fixed. Mathematically, it suffices to observe that a maximization problem may be formulated as the dual of the model which is a minimization problem. References 2 and 5 provide the mathematical development of the duality concepts. Certain shadow prices ($v_1, v_2, \ldots, v_n, v_{n+1}^{(1)}, \ldots, v_{n+m+s}^{(r)}$), one of which will be associated with each output constraint and resource constraint, will be the solution variables for this dual of the original problem. What is now important is to be aware of the economic meaning of these values and to realize how management may use this information as a valuable aid in decision making.

In an economic sense, the shadow prices associated with the output constraints are an actual measure of the cost to produce one more item at optimality. A discussion of the use of these values is presented below when post-optimality analysis is considered. The shadow prices associated with the resource constraints are the values imputed to the resources at optimality. For instance, if the i^{th} resource at the k^{th} facility is millwright hours, the shadow price would be the value of one more millwright hour as a contribution to the overall measure of effectiveness. The economic connotation is clear, the shadow prices provide a

value measure of the resource inputs at the margin. Management now has at its disposal a very powerful means to make economic comparisons. An example should clarify this point. Suppose one category of overtime labor has an upper bound and costs \$8.50 per hour, but the imputed value for labor in this category is \$15 per hour. In this instance, management might be well advised to apply additional overtime in this category, or expand the number of billits. As an extension of this procedure, it would be possible to calculate the shadow prices for a whole sequence of resource levels for the i^{th} resource at the k^{th} facility holding other resources constant. This would result in a plot of the marginal value of the resource for a wide range of input levels. Following this procedure would give management a method to analyze the return on its investment in resources, not normally found in government activities.

The above discussion leads directly into a consideration of post-optimality analysis. It should be recalled that the model parameters are actually random variables. Therefore, it would be beneficial to perform a sensitivity analysis on selected parameters. By varying parameters, the effect on the optimal solution could be observed. Even if stochastic effects were not considered, the fluctuating economic situation might make it desirable to investigate the consequences of changing various parameters. Substituting $'P_{pj}^{(k)}$ for $P_{pj}^{(k)}$ for example, could well change the optimal solution. Various modifications could be made in this manner until it

is determined which subset of the parameters are the most sensitive. Additional statistical analysis may be indicated, to obtain tighter estimates for the parameters. Hence, sensitivity analysis can be used to reduce the uncertainty induced in the model by the use of expected values as parameter estimates.

The model can also be applied to more general problems than just planning. Many other items such as the effects of: wage increases, additional product requirements, and newly instituted agency policy, may be studied. As an example, consider a Federal agency which anticipates a complete revision of its hourly wage scale. The impact of this revision on the agency's production processes could be examined by inputting a complete new set of labor cost parameters to the model. A new and a more efficient production plan could be developed prior to the implementation of the wage changes. The model could also be of aid in making the transition from the plan currently in progress to the new plan as smooth as possible.

Following this same theme, management could find it beneficial to use the model and the information system described previously, to develop a meaningful dialogue between the planning staff and the facilities. Initially, if the normal procedure is followed, the facilities would submit their input parameters. Then the model would be developed and solved, and the central headquarters would return the planning documents to the facilities. Subsequent

to completing this first loop, the staffs at the facilities would review the plan for scheduling and inventory considerations. Based on this review, the facilities could resubmit revised sets of input parameters with any additional constraint information developed. A new problem would be formulated for solution, and then the second phase planning documents would be forwarded to the facilities. This process of reciprocating communications could continue until both central management and the production facilities were satisfied that the best possible production plan had evolved.

In the same manner, the shadow prices associated with the output constraints can be used to good advantage in extending the dialogue to consider the marginal cost of producing the various outputs. Once the dual problem is solved, the management of the central agency could study the listings of shadow prices. These would be the costs of producing one more item at the margin. If certain of these costs were found to be excessive, the problem could be reformulated with the output constraints associated with these costs established at lower levels. Additionally, if certain of the marginal costs were lower than anticipated, the model could be reformulated with the associated output levels raised. The new dual problem would be solved and the marginal ocsts of producing the outputs again studied. This procedure would continue until the management of the agency was satisfied that the most desirable set of production outputs had been reached.

One other area of significant application for the model should be discussed. This deals with the use of the model for capital investment decisions. Specifically two areas will be addressed, investment in technologically new production processes and secondly, investment in those resources which could be considered real assets such as lathes or milling machines. Much light could be shed on the question of the desirability of the introduction of a new production process, by formulating the appropriate process vector and inserting it in the model. The new optimal solution obtained and the resources consumed by the proposed production activity would provide the agency with substantial decision making information for a feasability study of the process.

In relation to decision for capital investment in resources, the information derived from the duality concepts could be very meaningful to management. The shadow prices would give the values of the input resources at the margin. By the use of these values and capital budgeting models the present-value of capital investments could be determined. The discounted present-value of the investment for a planning horizon of n periods and for the i^{th} resource is defined as:

$$PV_i = \sum_{t=0}^{n} \frac{S_{t_i} - C_{t_i}}{(1+I)^t}$$

where S_{t_i} = the marginal revenue product or shadow price of the i^{th} resource in the t^{th} period,

C_{t_i} = the cost of the investment for i^{th} resource in the t^{th} period,

I = the interest rate

Using this method, realistic pairwise comparisons could be made among alternative resource investments. This procedure assumes no change in basis and the same interest rate over time. In an applied problem these assumptions may prove restrictive. Reference 2 provides a discussion of the discounted present-value criterion.

IV. AN APPLICATION OF THE MODEL TO THE PLANNING OF THE MARINE CORPS DEPOT MAINTENANCE PROGRAM

A. BACKGROUND

1. Repair Programs

This chapter has been incorporated into the thesis to provide a preliminary study of an actual planning situation to which the decision model could be applied. The problem chosen for examination is that of planning the Marine Corps' annual maintenance and repair program for major end items of equipment. Consideration will be given to model development, data sources and parameter estimation, and utilization of the model as a management tool.

Marine Corps equipment includes a variety of different types such as engineering, communications--electronics, and motor transport. Due to usage and age, all of this equipment finally reaches the point where it must be repaired or replaced. It has been determined that in many instances it is more advantageous for the Marine Corps to overhaul and rebuild its equipment rather than institute new procurement on the open market. The agency which has overall responsibility for the development and management of the annual repair program is Headquarters Marine Corps (HQMC). Specific cognizance over the program is maintained by the G-4 and Quartermaster General Sections of HQMC.

Currently the development of rebuilt requirements and the detailed planning of the annual repair program are

accomplished by the above mentioned sections and the Supply Inventory Control Point (ICP), Philadelphia. The overall repair program is divided into two separate entities, the Commandant of the Marine Corps (CMC) repair program and the Secondary Repairable Items Program. The former program concerns itself with principle items of equipment and the latter with major equipment components such as transmissions and engines. Certain equipment and maintenance management programs provide the physical assets which are the inputs to these repair programs.

A major source of repairable input assets to the CMC Repair Program is from the Replacement and Evacuation (R&E) Program. This program is intended to extend the service life of Marine Corps equipment by providing for its timely replacement and evacuation for rebuild on a cyclic basis. Initiation of the R&E Program occurs when the G-4 Section of HQMC forwards to the operating units in the field technical criteria for rebuild. These criteria could include such items as age, hours of operation, or time spent in Southeast Asia. The field would then return its rebuild requirements to the G-4 Section, HQMC, based on the established criteria. There the technical sections develop priority listings of the requirements and forward them to the Quartermaster General Section.

The second source of repairable assets for the CMC Repair Program is the Recoverable Items Program (RIP). This program has been established to provide the policy and

procedures for the recovery of principle repairable items of Marine Corps equipment that are predetermined to be economically repairable and/or excess to the needs of the using unit. A prime example of items which would fall within this program are retrograde items from Southeast Asia which are still repairable. Together then, the R&E and RIP programs are the principle source of input for the CMC Repair Program.

A third component of the input to the overall Marine Corps Repair Program deals not with major items, but with secondary items. This program is designed to insure that when unserviceable secondary items require repair, serviceable items will be made available on an exchange or rapid turn around basis. In this way, the parent equipment will be permitted to remain operational with a minimum of downtime.

Repair requirements from the various programs are collected and documented by HQMC or its representatives. Then the Quartermaster General's Section, in conjunction with other appropriate sections, begin the development of the annual repair program. Here the rebuild requirements are analyzed, based on their contribution to the Marine Corps mission, status of equipment inventories, and many other factors, in a bargaining process staffed by the interested parties of the logistics and supply fields. Participants in this bargaining process weigh the alternatives of which items to rebuild and how many of each item.

From this procedure, a repair plan for the coming fiscal year evolves based on some collective utility function for the group. After this plan is formalized it is referred to as the CMC Master Work Schedule

2. Repair Facilities

A large majority of the rebuild capability within the Marine Corps is provided by its two Depot Maintenance Activities (DMA) located at the Supply Centers in Albany, Georgia and Barstow, California. These two activities are the "production" facilities where the repair of major equipment is accomplished. Production planning for each of these facilities, in the sense of the items to be rebuilt, is carried out by HQMC. The mission of these two facilities is to provide the Commandant of the Marine Corps with the capability to completely overhaul principle items of equipment and secondary repairable items. It is considered that the repair programs at these facilities are a major source of supply for the aforementioned items with particular emphasis on timely responses to the mission oriented requirements of the Marine Corps.

The organizational structure of the two Depot Maintenance Activities are similar. There is a shops branch set up along functional lines to accomplish the productive work and certain other branches, fulfilling the required staff functions. A predominantly civilian force is employed with a military director as facility manager. Of particular interest is the availability of sophisticated computer

capability to the staff of the DMA's. This is provided by the IBM-360 computer which is installed in the Data Processing Facility of the Supply Center on which the DMA's are located. Reference 8, the Depot Maintenance Activities Management Manual, delineates the basic operational policy for the DMA's

Financial management and control of the DMA's is in accordance with the Marine Corps Industrial Fund (MCIF) concepts. Reference 9, the Marine Corps Industrial Fund Handbook, documents these concepts. The MCIF is a revolving type of working capital and was established for each DMA in July 1968. Implementation of Industrial Funding at these two activities has caused them to be subjected to a much more rigorous cost accounting system. In conjunction with this improvement, a more detailed data collection system was installed for the recording of hours worked against active job orders for the repair of equipment. This system utilizes the computer mentioned above and consists of a set of data input stations throughout the repair facility where the employees punch on and off of specific job orders. Once a job order is completed, the customer concerned is billed for the repair work accomplished on his equipment. All work accomplished by the DMA's is on a reimbursable basis. This includes maintenance done for HQMC on the Master Work Schedule. Figure 3 shows the financial cycle of operation for the DMA's.

It should be noted that the actual workload of the DMA's is divided into two categories, CMC directed work and

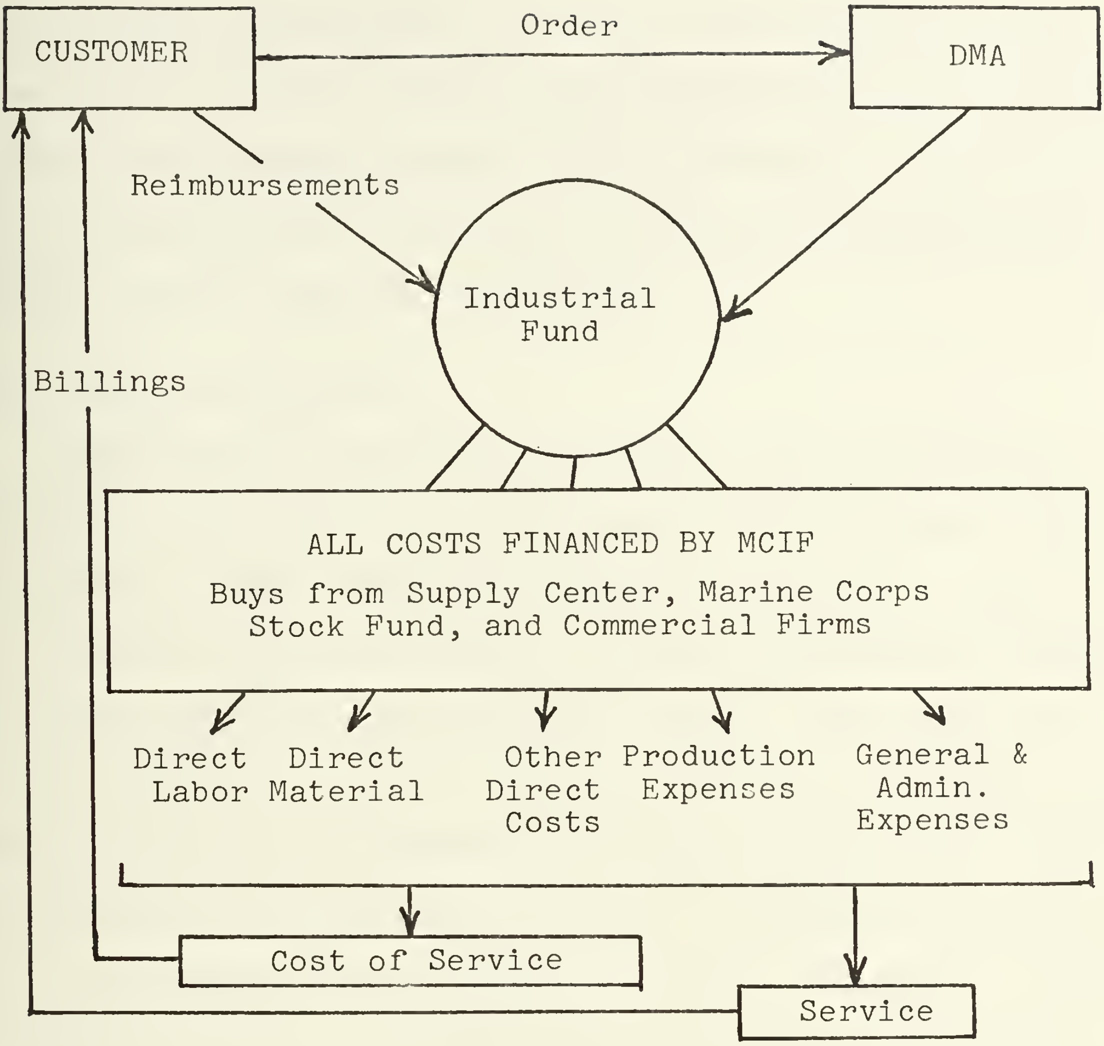

Figure 3. Cycle of Operations Under USMC Industrial Fund Financing

supply center support requirements. The CMC directed work consists generally of the repair programs previously mentioned and is directed on an annual basis by HQMC. The supply Center Support Program consists of care-in-storage for major items and preparation-for-shipment of these items. These are functions of the supply centers themselves and hence they are responsible for the development of these programs. Again this work is reimbursable for the DMA's.

Procedures are available to project that portion of the maintenance effort directed toward CMC requirements. This enables the planning model for the CMC Repair Program to be developed while excluding from further consideration supply center support requirements.

B. DECISION SITUATION

Consider the situation presented in the previous section for the planning and development of the annual repair program by HQMC. Once the bargaining process is concluded, the result would be a vector of repair requirements including both principle and secondary items. This vector, in fact, represents the desired outputs from the Marine Corps Depot Maintenance Program for the next fiscal year. To accomplish this maintenance effort, the Marine Corps has at its disposal several alternate repair procedures. These alternatives are: accomplishment of repair work by the two DMA's, utilization of the depot maintenance capabilities of other government agencies, and contracting the required overhaul work to industrial firms engaged in this type endeavor.

At this juncture it is suggested that the repair program planners should have a specific management objective in mind before proceeding in the decision process. Formalized, this objective would be: given a vector of desired outputs, distribute these outputs as production requirements among the production alternatives in such a way as to minimize cost.

The mathematical model developed in the next section is intended to provide solutions to this decision problem.

C. FORMULATION OF THE DECISION MODEL

Generally the formulation of this model will be similar to the cost minimization model developed in Chapter II. A total of n items of equipment requiring repair will be addressed by the model. The model will concern itself with the two DMA's as production facilities and L-2 alternate repair activities. These would include both governmental and industrial concerns capable of the desired repair. Consideration of all variable production costs for the DMA's will be included in the objective function. Additionally, contract costs for repairs accomplished by alternate activities will be reflected in the cost function. It will be the overall goal of the mathematical model formulated to minimize this objective function.

Resource constraints for the model will be divided into two sets, those for the productive labor shops and those for other scarce resources such as materials. There will be a labor constraint for each productive shop such as the tracked vehicle shop or the power train shop. It is assumed that there are m of these constraints. A set of s constraints is formulated to consider scarce resources other than labor, such as facilities, capital, and materials. An example could be the limited capacity of paint-spray booths.

Policy constraints similar to those presented in Chapter III may be introduced into the model on an as required basis.

However, there is one other type of constraint which is formulated for the model. This is a set of restraints which restricts the range of the output decision variables of the mathematical program. Incorporation of this set of constraints is necessitated by the mission oriented lower bounds imposed for each item repaired. Additionally, an upper bound is required for each item due to the limited number of repairable assets available for any planning period. The mission oriented lower production bounds are incorporated in the requirements vector. Upper production bounds are explicitly included in the model as less than or equal to constraints. The j^{th} constraint in this set is indicated as $\sum_{k=1}^{L} x_j^{(k)} \leq U_j$; where U_j equals the upper bound for the j^{th} item repaired.

The process vector concept is also included in this model. A complete set of vectors is formulated representing the technology of repair for all n items at both DMA's. The superscripts (1) and (2) will represent Albany and Barstow respectively.

Using the notions developed above, the mathematical statement of the cost minimization decision model is,

Minimize:

$$Z = \sum_{k=1}^{2} \sum_{i=1}^{m} \left[P_{Ri}^{(k)} \alpha_i^{(k)} w_i^{(k)} + P_{oi}^{(k)} O_{ti}^{(k)} \right]$$

$$+ \sum_{k=1}^{2} \sum_{i=m+1}^{m+s} P_i^{(k)} R_i^{(k)} + \sum_{k=3}^{L} \sum_{j=1}^{n} x_j^{(k)} P_{pj}^{(k)}$$

Subject to

$$\begin{array}{c} x_1^{(1)} \\ \\ \cdot \\ \\ \cdot \\ \\ \cdot \\ \\ x_1^{(1)} \end{array} \left[\begin{array}{c} V_{11} \\ \\ \\ \\ \\ \\ \\ \\ \\ \end{array}\right] \begin{array}{c} +\, x_2^{(1)} \\ \\ \cdot \\ \\ \cdot \\ \\ \cdot \\ \\ +\, x_2^{(1)} \end{array} \left[\begin{array}{c} V_{12} \\ \\ \\ \\ \\ \\ \\ \\ \\ \end{array}\right] \begin{array}{c} + \cdots + x_n^{(2)} \\ \\ \cdot \qquad \cdot \\ \\ \cdot \qquad \cdot \\ \\ \cdot \qquad \cdot \\ \\ + \cdots + x_n^{(2)} \end{array} \left[\begin{array}{c} V_{2n} \\ \\ \\ \\ \\ \\ \\ \\ \\ \end{array}\right] \begin{array}{l} + x_1^{(3)} + \cdots + x_1^{(L)} \geq x_1^* \\ \vdots \\ + x_n^{(3)} + \cdots + x_n^{(L)} \geq x_n^* \\ \leq \alpha_1^{(1)} w_1^{(1)} + O_{t1}^{(1)} \\ \leq \alpha_2^{(1)} w_2^{(1)} + O_{t2}^{(1)} \\ \vdots \\ \leq \alpha_m^{(2)} w_m^{(2)} + O_{tm}^{(2)} \\ \leq R_{m+1}^{(2)} \\ \vdots \\ \leq R_{m+s}^{(2)} \end{array}$$

$$\begin{array}{r} w_1^{(1)} \leq {}^*w_1^{(1)} \\ \vdots \\ w_m^{(2)} \leq {}^*w_m^{(2)} \end{array}$$

$$\sum_{k=1}^{L} x_j^{(k)} \leq u_j, \; j = 1,2,\ldots,n;$$

$x_j^{(k)} \geq 0, \quad j=1,2,\ldots,n, \quad k=1,2,\ldots,L;$

$w_i^{(k)} \geq 0, \quad i=1,2,\ldots,m, \quad k=1,2;$

$O_{ti}^{(k)} \geq 0, \quad i=1,2,\ldots,m, \quad k=1,2;$

$R_i^{(k)} \geq 0, \quad i=m+1,m+2,\ldots,m+s, \quad k=1,2.$

where

Z = the total cost to repair and/or contract for repair of a given vector of output requirements $(x_1^*, x_2^*, \ldots, x_n^*)$,

$x_j^{(k)}$ = the output level of the j^{th} repair process at the k^{th} facility,

$P_{Ri}^{(k)}$ = the cost of one hour of the i^{th} regular time labor resource at the k^{th} activity,

$P_{oi}^{(k)}$ = the cost of one hour of the i^{th} overtime labor resource at the k^{th} activity,

$P_i^{(k)}$ = the cost of one unit of the i^{th} scarce resource other than labor at the k^{th} activity,

$P_{pj}^{(k)}$ = the contract price of repair for the j^{th} item from the k^{th} alternate production activity,

$\alpha_i^{(k)}$ = the number of man hours per man available for the i^{th} labor resource at the k^{th} activity during the planning period,

$w_i^{(k)}$ = the number of men utilized for the i^{th} labor resource at the k^{th} activity,

$O_{ti}^{(k)}$ = the number of hours of the i^{th} labor resource utilized on an overtime basis at the k^{th} activity,

$R_i^{(k)}$ = the amount of the i^{th} resource other than labor utilized at the k^{th} facility,

x_j^* = the lower bound for the production output of the j^{th} item,

U_j = the upper bound on the production output of the j^{th} item,

${}^*w_i^{(k)}$ = the number of men available for the i^{th} labor resource at the k^{th} facility,

$d_{ij}^{(k)}$ = the amount of the i^{th} limited resource other than labor required to repair one unit of the j^{th} output at the k^{th} facility,

$a_{ij}^{(k)}$ = the amount of the i^{th} labor resource required to repair one unit of the j^{th} output at the k^{th} facility.

It should be noted that the last two quantities defined, $a_{ij}^{(k)}$ and $d_{ij}^{(k)}$ are the technological coefficients of the process vectors, the V_{ij}'s. These two quantities are input

parameters to the program. Additional model parameters are $P_{Ri}^{(k)}$, $P_{oi}^{(k)}$, $P_{i}^{(k)}$, $P_{pj}^{(k)}$, $\alpha_{i}^{(k)}$, x_j^*, U_j, and $^*w_i^{(k)}$. The decision variables of this formulation are the $R_i^{(k)}$'s, $x_j^{(k)}$'s, $O_{ti}^{(k)}$'s, and $w_i^{(k)}$'s. As in the model developed in Chapter II, it is assumed that the cost of overtime labor is greater than the cost of regular time labor.

In an effort to add realism to the model, certain of the outputs of the repair processes will now be delineated. The possibilities for these decision variables are as follows:

$x_1^{(1)}$ = the output level of ONTOS, M50A1 (self-propelled anti-tank weapon) at Albany,

$x_1^{(2)}$ = the output level of ONTOS, M50A1 (self-propelled anti-tank weapon) at Barstow,

$x_2^{(1)}$ = the output level of LVT'S-P5A1 (amphibious tractor) at Albany,

$x_2^{(2)}$ = the output level of LVT'S-P5A1 (amphibious tractor) at Barstow,

.
.
.

$x_j^{(1)}$ = the output level of trucks M35A2C at Albany,

$x_j^{(2)}$ = the output level of trucks M35A2C at Barstow,

.
.
.

$x_n^{(L)}$ = the output level of tanks, 90MM Gun M48A3 at the U.S. Army Depot; Anderson, Alabama.

These possibilities are by no means to be considered binding specifications. They are simply presented as being

representative of the hundreds of items the Marine Corps must repair each year. Additional decision variables could be introduced in the model to account for various repair processes depending on the Condition Code of the item.

D. DATA COLLECTION AND ESTIMATION OF MODEL PARAMETERS

Data collection and parameter estimation for this model would require a great deal of research and detailed statistical work. However, it is made somewhat easier by the implementation of the Marine Corps Industrial Funding and the availability of the data processing capability mentioned previously. Currently a large data base is being built up as a result of managerial and cost accounting procedures incorporated in the industrial funding program. It is envisioned that with proper systems design and programming, the computer capability at each supply center could be utilized to assimilate relevant portions of this data and make the required statistical calculations. In the cases where appropriate parameter estimates would be generated by way of expected values, the methods discussed in Chapter III would be applicable. Below are listed the model parameters and their data sources. Note that the data sources are currently available without further analysis and design work. Additionally, representative parameter estimates are displayed in some instances. Any management report referenced will be available at both of the Depot Maintenance Activities.

The input parameter to the model and their associated data sources are as follows:

$P_{Ri}^{(k)}$ - (Regular time labor cost) - This could be obtained from currently existing labor rate schedules. It is the cumulative total of the basic wage, benefits, and an appropriate prorated portion of the overhead costs. Examples of these values as extracted from budgetary documents at Albany during May 1970 are presented in Table I.

TABLE I

SAMPLE REGULAR TIME LABOR COST PARAMETERS FOR THE DEPOT MAINTENANCE ACTIVITY, ALBANY, GEORGIA

PARAMETER		HOURLY RATE	SHOP
$P_{R11}^{(1)}$	=	\$12.21	723
$P_{R20}^{(1)}$	=	\$13.56	745
$P_{R24}^{(1)}$	=	\$11.56	761

$P_{oi}^{(k)}$ - (Overtime labor cost) - This also could be obtained from the labor rate schedules. It includes all items mentioned above for the regular time cost plus the overtime rate. Examples of these values as extracted from budgetary documents at Albany during May 1970 are presented in Table II.

TABLE II

SAMPLE OVERTIME LABOR COST PARAMETERS FOR THE DEPOT MAINTENANCE ACTIVITY, ALBANY, GEORGIA

PARAMETER		HOURLY RATE	SHOP
$P_{o11}^{(1)}$	=	\$14.33	723
$P_{o20}^{(1)}$	=	\$16.38	745
$P_{o24}^{(1)}$	=	\$13.82	761

$P_i^{(k)}$ - (Cost of scarce resources other than labor) - Input materials costs for separate items could be extracted from the federal supply catalogs listings in effect for the planning period. Total materials cost per repaired output item can be projected statistically from data on the Depot Maintenance Activity Management Report A-1. Any variable costs associated with production equipment or facilities could be estimated by the Industrial Engineering Branches at the DMA's.

$P_{pj}^{(k)}$ - (Contracted cost of repair at an alternate activity) - Bids for repair by alternate agencies and firms could be centrally collected by HQMC for input into the model.

$*w_i^{(k)}$ - (Available manpower for the i^{th} labor resource) - This could be statistically projected using data extracted from the Maintenance Management Report 3-3. Representative parameter estimates extracted for Albany during November

1969 are presented in Table III. These estimates are for a period of one year.

TABLE III

SAMPLE LABOR RESOURCE PARAMETERS FOR THE DEPOT MAINTENANCE ACTIVITY, ALBANY, GEORGIA

LABOR RESOURCE		MAN EQUIVALENTS	DMA SHOP NUMBER
$*w_{1}^{(1)}$	=	0.275	608
$*w_{2}^{(1)}$	=	0.020	612
$*w_{3}^{(1)}$	=	0.284	613
$*w_{4}^{(1)}$	=	0.306	614
$*w_{5}^{(1)}$	=	0.425	615
$*w_{6}^{(1)}$	=	0.346	618
$*w_{7}^{(1)}$	=	0.030	625
$*w_{8}^{(1)}$	=	0.665	681
$*w_{9}^{(1)}$	=	0.128	682
$*w_{10}^{(1)}$	=	44.510	721
$*w_{11}^{(1)}$	=	14.820	723
$*w_{12}^{(1)}$	=	3.970	724
$*w_{13}^{(1)}$	=	22.050	731
$*w_{14}^{(1)}$	=	18.530	732
$*w_{15}^{(1)}$	=	29.650	733
$*w_{16}^{(1)}$	=	6.450	734
$*w_{17}^{(1)}$	=	8.950	738
$*w_{18}^{(1)}$	=	21.090	742
$*w_{19}^{(1)}$	=	25.410	744

$\alpha_i^{(k)}$ - (Available man hours per man for the planning period) - This could be statistically projected using currently existing labor audits. For its yearly planning purposes Albany currently (May 1970) projects this at $\alpha_i^{(1)} = 1664$, for all i.

U_j - (Upper output bound) - Conceptually this information on repairable assets could be extracted from the output data of Sub-Systems 13 and 03 of the Marine Corps' Unified Material Management System (MUMMS).

$a_{ij}^{(k)}$ - (Labor technological coefficients) - This set of parameters could be statistically projected from data on the Maintenance Management Report 3-2. For example, the vector of coefficients for the repair of an ONTOS, M50A1 extracted at Albany during November 1969 is presented in Table IV.

$d_{ij}^{(k)}$ - (Technological coefficients for resources other than labor) - Estimates of these parameters would have to be extracted from existing Industrial Engineering studies or from studies specifically designed for this purpose.

E. A PROPOSED INFORMATION AND DECISION SYSTEM BASED ON THE MODEL

The same type argument presented in Chapter III for the integration of the model into a management information and decision system (MI&DS) is applicable in this instance. By using a support system specifically designed for the decision model HQMC could realize the greatest possible

TABLE IV

SAMPLE LABOR TECHNOLOGICAL COEFFICIENTS FOR THE DEPOT MAINTENANCE ACTIVITY, ALBANY, GEORGIA

COEFFICIENTS		MANHOURS/ONTOS	DMA SHOP NUMBER
$a_{10,1}^{(1)}$	=	565.4	721
$a_{11,1}^{(1)}$	=	76.8	723
$a_{12,1}^{(1)}$	=	69.8	724
$a_{14,1}^{(1)}$	=	108.9	732
$a_{15,1}^{(1)}$	=	57.1	733
$a_{16,1}^{(1)}$	=	6.9	734
$a_{18,1}^{(1)}$	=	36.7	742
$a_{19,1}^{(1)}$	=	141.1	744
$a_{21,1}^{(1)}$	=	4.4	751
$a_{22,1}^{(1)}$	=	91.3	755
$a_{23,1}^{(1)}$	=	117.8	756
$a_{24,1}^{(1)}$	=	73.8	761
$a_{25,1}^{(1)}$	=	85.7	763
$a_{26,1}^{(1)}$	=	19.5	765
$a_{27,1}^{(1)}$	=	14.1	766

benefit from it. Input information to this system would be primarily "borrowed" from existing systems and forwarded to HQMC. Sources of data for input parameters would be those indicated above. Additionally HQMC would have to input the repair requirements vector and formulate any necessary policy or mission oriented constraints. The model would then be established on a digital computer for solution at some convenient location. It is envisioned that for a given fiscal year there would be from 300 to 500 decision variables in this linear program with approximately the same number of constraints. Once solutions were provided from the model, they would become the Marine Corps Repair Program for the coming fiscal year. Each DMA would then be forwarded its operations plan for the next production period and contracts could be written to purchase the production capabilities of the alternate repair facilities. Outlined in Figure 4 is a diagrammatic sketch of the MI&DS.

F. THE SYSTEM AND MANAGEMENT

1. Management Significance of the Model

Probably the most important single benefit derived from the model would be the output of the decision variables from which the production programs would be generated. The duality concepts presented in Chapter III would be applicable here. Of particular interest to HQMC would be the dual variables associated with the production output constraints. These values would be the shadow prices or marginal costs,

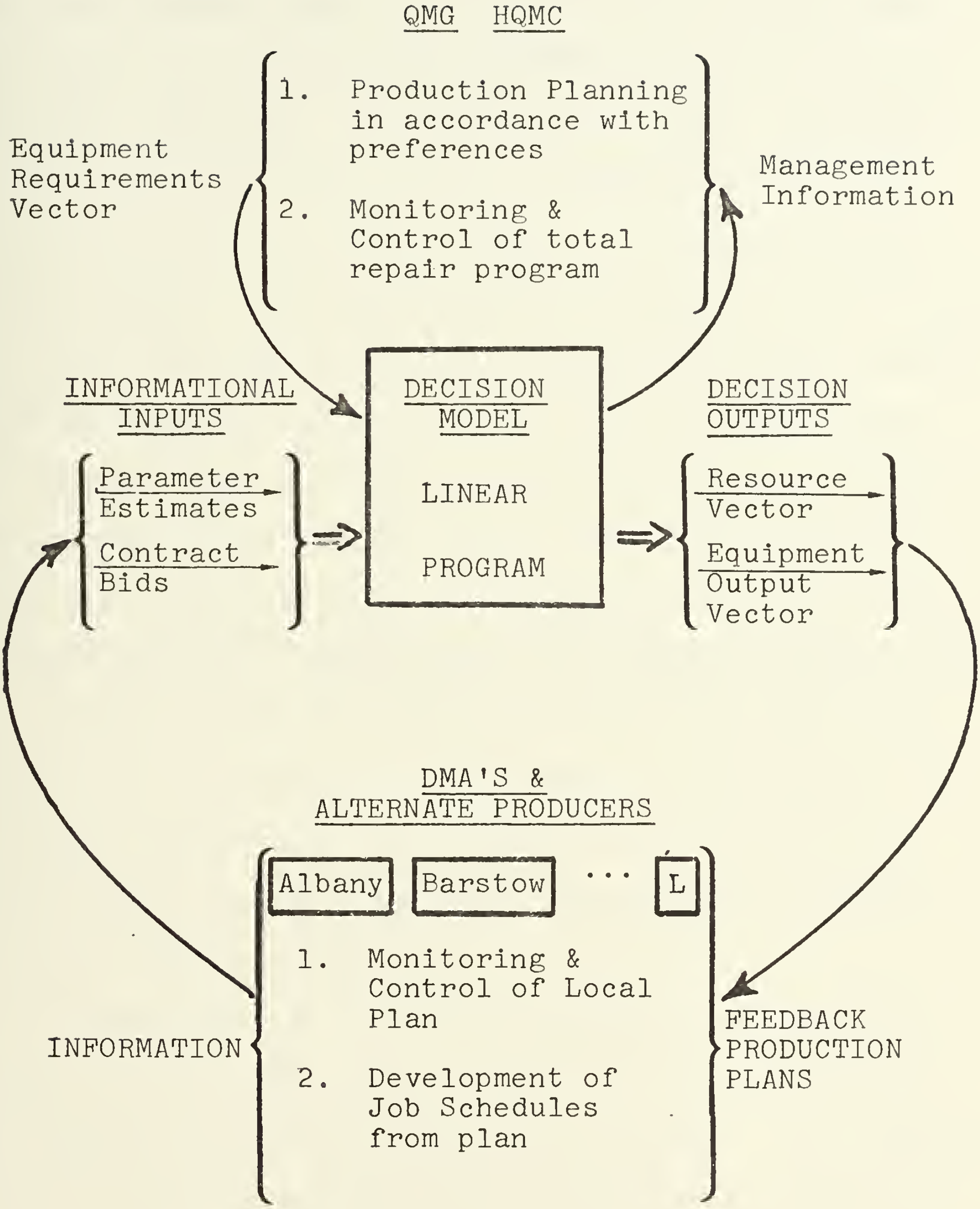

Figure 4. Depot Maintenance Management Information and Decision System for the Marine Corps

for the output of one more unit of a particular line item of equipment. For a specific formulation of the model with its established output levels, the HQMC planners could study these costs and determine line item by line item if these costs were consistent with their preferences. Subsequent to this review the model could be reformulated with the output constraints raised or lower as deemed appropriate by the planners. The model would be resolved and the shadow prices for the production output constraints again studied. This process would continue until a set of output levels evolved which were consistent with the preferences of the HQMC planners. The question of the effective employment of additional resources could also be studied by the use of the shadow prices. Comparison of the relative worth of the input resources could be made by using these values as described in Chapter III. The financial management of investment capital could be enhanced by the use of the shadow prices and the discounted present-value criterion developed in Baumol [Ref. 2].

A secondary use of the MI&DS could be to establish a dialogue between HQMC and the DMA's for the development of the production plans by an iterative process. The procedure would be to submit the parameters through the information system, solve the program, and return the production plans to the DMA's. Following the review of the plan by the repair facilities for inventory and scheduling considerations, additional parameters and constraints could be forwarded to

HQMC. This process would continue until the most favorable plan possible had been reached.

Mention should also be made of one other problem on which the model could shed meaningful management light. This is the problem of staying within the budgetary limitation for depot type maintenance within the Marine Corps. Although the model minimizes cost, there is no guarantee that the resulting plan generated will be feasible financially. Here again a colloquy with the model could be used to good advantage. Should the initial vector of output repair requirements lead to a financially infeasible solution, a new requirements vector could be formulated and input to the model. In fact, a whole series of requirements vectors might be developed, input to the model, and the solutions recorded. Using this approach, the financial feasibility bounds on the problem could be determined. Eventually a decision would be made to select one requirements vector from the group of feasible solutions.

2. A Normative Implication of the Model

Presentation will now be made of a point of management interest which may be implied from the conceptualization of the model. This topic relates to the use of the appropriate variable costs as inputs to the decision model. Variable in this context refers to the costs which are associated directly with production. Stated simply, the principles underlying the model lead one to the conclusion that the economically correct totality of costs for

repair are not reflected in the DMA's billing of their customers.

In this case of total repair costs, current policy dictates that these expenses be divided into "direct costs" and "indirect costs." Indirect costs consist of military labor and a certain category of supply items referred to as ASA materials. As reflected by Figure 2, the Industrial Funding flow chart, the indirect charges are not billed to the customer. On an individual item basis, this practice prevents an economically meaningful comparison to be made between repair at the DMA's and repair at the alternate facilities. Additionally, when collective costs are considered for all production processes at the several facilities, it is obvious that exclusion of the indirect costs will lead to a much lower total production cost than when these costs are included. This means that, $z' \ll z$, i.e. that the "optimal" total cost of production will be much less when indirect costs are not included in the objective function. To indicate how these costs vary, several examples for the 1968 fiscal year at Albany are listed below. These repair costs, extracted from the DEPOT MAINTENANCE ACTIVITY MANAGEMENT REPORT (A-1) of 30 September 1969, reflect actual average cost of repair per unit and are presented in Table V. If a sound economic analysis is to be made of the total production system, all variable costs, including indirect costs, would have to be considered. Hence, model parameters should reflect these aggregate costs.

TABLE V

AVERAGE COST OF REPAIR PER UNIT FOR CERTAIN MARINE CORPS LINE ITEMS OF EQUIPMENT, DURING THE 1968 FISCAL YEAR AT THE DEPOT MAINTENANCE ACTIVITY, ALBANY, GEORGIA

REPAIR ITEM NOMENCLATURE	TOTAL FUNDED COST (CHARGED TO CUSTOMER)	OTHER COSTS (NOT CHARGED)	TOTAL COST
Truck Dump M-51	$4,808	$ 565	$5,373
Generator Set PU-590M	$4,906	$ 604	$5,510
Fork Lift 3000 lb.	$4,627	$1283	$5,910

V. SUMMARY AND CONCLUSIONS

The models structured in the thesis are presented as mathematical tools to aid management in the decision making process. However they play an even more basic and important role. This is because in model formulation a logical framework is developed in which a scientific methodology may be applied to decision making. One is forced to consider the bounds, resources, and constraints of the problem. The requirement for model parameters point out the need for management information, and causes research to be done on data sources and their validity. Finally the model clearly indicates the need for concise and well-defined objectives in the planning of operations for an organization. This is one of the greatest merits of scientific models.

Obviously the models developed do not take under consideration all relevant topics of management interest. Specifically, problems of inventory control and production scheduling were not addressed in the model. However it was suggested that the model could be used to develop a dialogue between the central headquarters and the production facilities to consider these items. Utilized in this way, the models developed have the inherent responsiveness to give meaningful guidance to management.

The possibility of model implementation opens a whole new field of concern. Feasibility studies would have to be carried out for each new organization considered. It would

be necessary to weigh the anticipated benefits from the model against the cost of developing and operating it. In the case of the model structured for the Marine Corps, the benefits of the production plans and other decision making information would have to be economically compared to the expense of implementation and operation. Systems design work, hardware, and personnel are only a few of the areas in which costs would have to be considered. Additionally, it is evident that it might be quite difficult to economically quantify the benefits derived from the model to make objective comparisons.

Mention should be made of the possible further utilization of the maximization of effectiveness model. It will be remembered that this formulization was abandoned when the difficulties in quantifying utility measures were encountered. Many of the problems associated with this model would be eliminated if the decision environment was one where the monetary unit of exchange was the utility measure. This clearly points towards the consideration of the problem in a more competitive situation than is available in the constrained economic surroundings of the agency. This would require the establishment of a market value for items to be produced or repaired. Conceivably for certain classes of items, this could be done. These would be items which were being produced by several different industrial firms and which could be depreciated over time using Industrial Engineering principles. Electronics equipment, motor

transport, and engineering equipment could be examples. However, the establishment of market values for such items as attack aircraft and artillery could be much more difficult.

The notions developed in this thesis provide a broad foundation for further study. Recommended topics for additional consideration are the detailed development of a management information system to support the model, the formulation of the model for other real world problems such as the planning of the maintenance program for Naval Aviation, and the development of additional statistical analysis techniques to support parameter estimation for the model. Certainly this is not a comprehensive list, but it does indicate the scope of possible future study.

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BSTRACT

A decision model is formulated for the planning of production for a large centrally managed governmental agency with multi-production facilities. The concepts of linear economics and mathematical programming are utilized to develop the model as a single-period planning tool for the efficient allocation of resources and production effort. It is assumed that the governmental agency desires to optimize the conversion of its input resources to outputs for all its production facilities. Under this assumption, the two separate problems of effectiveness maximization and cost minimization for the agency as a whole are considered. The questions of data collection, parameter estimation, and management utilization of the model are also addressed. A specific formulation of the model is presented for the decision problem of the maintenance and overhaul of the major end items of equipment within the logistical system of the Marine Corps.

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